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The efficacy of functional gait training in children and young adults with cerebral palsy: a systematic review and meta-analysis

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ABBREVIATIONS

MCID	Minimal clinically important difference
OGT	Overground gait training
PBWS	Partial body weight support
PBWSTT	Partial body weight support treadmill training

AIM The aim of this systematic review was to investigate the effects of functional gait training on walking ability in children and young adults with cerebral palsy (CP).
METHOD The review was conducted using standardized methodology, searching four electronic databases (PubMed, Embase, CINAHL, Web of Science) for relevant literature published between January 1980 and January 2017. Included studies involved training with a focus on actively practising the task of walking as an intervention while reporting outcome measures relating to walking ability.
RESULTS Forty-one studies were identified, with 11 randomized controlled trials included. There is strong evidence that functional gait training results in clinically important benefits for children and young adults with CP, with a therapeutic goal of improved walking speed. Functional gait training was found to have a moderate positive effect on walking speed over standard physical therapy (effect size 0.79, p=0.04). Further, there is weaker yet relatively consistent evidence that functional gait training can also benefit walking endurance and gait-related gross motor function.
INTERPRETATION There is promising evidence that functional gait training is a safe, feasible, and effective intervention to target improved walking ability in children and young adults with CP. The addition of virtual reality and biofeedback can increase patient engagement and magnify effects.

Cerebral palsy (CP) is an umbrella term for a group of disorders caused by brain malformation or damage during early development, with the defining characteristic of motor and posture impairment that limits activities of daily living and self-care. It is the most common cause of long-term childhood disability, impacting 2.1 per 1000 live births.[1] Children with CP are often classified by severity of mobility limitation through the Gross Motor Function Classification System (GMFCS).[2] This is a useful tool to identify levels of motor ability, guide treatment decisions, and allow estimation of the development of motor performance.[3] Children categorized in GMFCS levels I and II can walk unassisted, whereas those in levels III to V require assistive devices such as walkers or a wheelchair for functional mobility.[2] A common therapeutic goal for rehabilitation is to improve mobility and walking ability. Improved walking ability has a positive impact on achievement of daily activities and motivating social engagement.[4] While CP is a non-progressive neurological disorder, without treatment severity of motor impairment can progress, leading to reduced physical activity and further complications in adult life.[5,6] A wide range of interventions are used to treat the symptoms that CP affects, with some showing more success than others.[7] There has been a progression from traditional impairment-focused therapeutic intervention, such as increasing muscle strength and range of motion, to treating functional elements of activity and participation, following the International Classification of Functioning, Disability and Health framework.[8] This change in thinking is coupled with a greater understanding of motor learning mechanisms, with the use of repetitive, task-specific movements beneficial to restructuring motor pathways.[9,10] Functional gait training allows for repetition of motor task to drive skill acquisition.[11,12] Targeting improved walking ability, with training, may lead to gains in increased independence and follow with increased participation in daily life.

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Functional gait training encompasses a range of diverse interventions with the same treatment goal. It can be defined as actively practising the task of walking, to improve walking ability. This can involve overground gait training (OGT) or treadmill-based gait training. The addition of a treadmill allows a greater repetition of stepping in a safe, controlled environment, increasing intensity, compared with OGT.[13] Both methods may incorporate the use of partial body weight support (PBWS) systems. PBWS acts to reduce load on lower limbs, allowing upright posture and gait facilitation. This could be important for individuals in GMFCS levels III and IV, where self-driven gait training would be challenging without intensive facilitation from therapists. Following motor learning principles, intensity, duration, and variability in intervention are important to drive retention of treatment effect. The addition of virtual reality helps to increase engagement, particularly in paediatric rehabilitation programmes.[14] Furthermore, the development of extensive methods of biofeedback-assisted rehabilitation[15] can be valuable in supporting patients and allowing therapists to communicate treatment goals more effectively. Currently there is no established optimal protocol for gait training as an intervention in children and young adults with CP, with limited comparison between gait training methods in the literature and consequently no evidence about which method is most effective.

Literature investigating gait training reports a wide variety of interventions and outcome measures relating to an individual's walking ability, making it difficult to establish the true effect of intervention. Previous systematic reviews have focused on the use of partial body weight support treadmill training (PBWSTT), ultimately concluding that it is a safe and feasible treatment option for children with CP and with positive evidence reported.[16–18] Further, a recent update of the Cochrane review concluded that treadmill training interventions in children with CP under 6 years of age may accelerate motor skill attainment.[19] While evidence points towards beneficial effects of gait training, because of the lack of high-quality randomized controlled trials, until now there has been insufficient evidence to recommend its use in a clinical setting. Previous systematic reviews were limited by their focused scope in the definition of gait training and often reported only limited gait outcomes, as such not incorporating all the benefits that gait training in children and young adults with CP could bring. Since the publication of these reviews, further randomized controlled trials have been reported and therefore an update on the current level of evidence surrounding the use of gait training to treat walking ability in children and young adults with CP is required.

Therefore, the primary goal of this systematic review was to assess the effectiveness of functional gait training on gait-related outcome measures in children and young adults with CP. A secondary aim was to compare the efficacy of type of gait training intervention commonly implemented: namely, OGT, PBWSTT, treadmill training, and any added benefits of gait training enhanced with virtual reality and feedback. Electromechanical gait trainers[20] and functional electrical stimulation[21] can also be used to facilitate the motion of gait. These are end-effector devices used to simulate walking, which is inherently different in neural control to gait training in which gait is actively achieved by the patient.[22] Therefore, to isolate any effect, such assistive devices will not be considered in this review.

What this paper adds

- Functional gait training is a safe, feasible, and effective intervention to improve walking ability.
- Functional gait training shows larger positive effects on walking speed than standard physical therapy.
- Walking endurance and gait-related gross motor function can also benefit from functional gait training.
- Addition of virtual reality and biofeedback shows promise to increase engagement and improve outcomes.

METHOD

A systematic review was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[23] The original methodology of the systematic review, with a full list of search terms, was registered on PROSPERO and can be accessed online.[24]

Search strategy

A search of four databases (PubMed, Embase, CINAHL, Web of Science) was conducted. The search strategy was developed and refined in group discussion after preliminary searches. The final search strategy included a comprehensive list of terms relating to or describing the target population (cerebral palsy), intervention (training; or treadmill; or overground; or feedback; or virtual reality) and outcome (gait; or walk*).[24] There were no language or study design restrictions at the initial stage. Studies published between January 1980 and the search date (January 24th, 2017) were included. Additional supplementary material, through cross referencing, was sought if missed by initial search.

Study selection

Inclusion criteria included (1) children and young adults (5–25y) with CP, (2) gait training intervention with at least pre-/postmeasurement, and (3) reporting a gait-related outcome measure. Exclusion criteria included more than 30% of participants not meeting inclusion criteria, and an alternative main intervention such as orthopaedic surgery, robotic assistive device, functional electrical stimulation, strength or balance training. Titles and abstracts were screened by two authors (ATCB and PM) to identify potentially eligible studies. Any discrepancies in outcomes of initial screening were resolved in group discussion with all authors. Full texts of the selected studies were retrieved and independently assessed by two authors against previous inclusion/exclusion criteria. Any disagreements were discussed in group consultation.

Study design was assessed using the American Academy of Cerebral Palsy and Developmental Medicine appraisal, categorizing levels of evidence for group and single-subject research design[25] (Table I). Methodological quality was

Table I: Levels of evidence for group and single-subject design studies

Level of evidence	Intervention (group) studies	SSRD studies
I	Systematic review of RCTs Large RCT (with narrow confidence intervals) (n>100)	Randomized controlled N-of-1 (RCT), alternating treatment design, and concurrent or non-concurrent MBDs; generalizability if the alternating treatment design is replicated across three or more subjects and the MBD consists of a minimum of three subjects, behaviours, or settings. These designs can provide causal inferences
II	Smaller RCTs (with wider confidence intervals) (n<100) Systematic reviews of cohort studies 'Outcomes research' (very large ecological studies)	Non-randomized, controlled, concurrent MBD; generalizability if design consists of a minimum of three subjects, behaviours, or settings. Limited causal inferences
III	Cohort studies (must have concurrent control group) Systematic reviews of case–control studies	Non-randomized, non-concurrent, controlled MBD; generalizability if design consists of a minimum of three subjects, behaviours, or settings. Limited causal inferences
IV	Case series Cohort study without concurrent control group (e.g. with historical control group) Case–control study	Non-randomized, controlled SSRDs with at least three phases (ABA, ABAB, BAB, etc.) Generalizability if replicated across three or more different subjects. Only hints at causal inferences
V	Expert opinion Case study or report Bench research Expert opinion based on theory or physiological research Common sense/anecdotes	Non-randomized controlled AB SSRD; generalizability if replicated across three or more different subjects. Suggests causal inferences allowing testing of ideas

Level I evidence is the most definitive for establishing causality of intervention, with greatest reduction in bias, while level IV can hint at causality; level V suggests only the possibility. SSRD, single-subject research design; RCT, randomized controlled trials; MBD, multiple baseline design.

assessed by two authors following a modified version of the American Academy guidelines in the protocol laid out by Morgan et al.[26] with 17 questions for group designs and 14 questions for single-subject research design (Appendix S1, online supporting information). Differences were resolved between the two authors and further disagreements were discussed in group consultation. Interclass correlation was performed to assess the reliability of this questionnaire. Reported outcomes of levels of evidence I to III were used for the main synthesis of data, with the results of levels IV and V used to provide evidence to support conclusions.

Data extraction

Data extraction was completed by one author (ATCB) using a customized data extraction form (Appendix S1). Study characteristics were recorded and summarized. All reported gross motor and gait-related outcome measures were evaluated, and categorized according to the International Classification of Functioning, Disability and Health children and youth version code,[8] along with a summary of findings. The three main outcome categories assessed were (1) standardized tests for walking speed, such as the 10-metre walk test; (2) standardized tests for endurance, such as the 6-minute walk test; and (3) outcomes related to the gross motor function, such as the Gross Motor Function Measure (GMFM). The GMFM is separated into functional dimensions relating specifically to standing ability (dimension D) and walking ability (dimension E). These are all widely used, valid, and reliable measures of walking capacity in children with CP.[27] The results for the three outcome categories were compared against their minimal clinically important difference (MCID), which is the threshold for a change of outcome measure that has a meaningful effect for the patient, as established previously for CP.[28]

A meta-analysis to compare the difference between group means, after intervention, for the effect of gait training versus standard physical therapy and strength training on walking speed was conducted using meta-analysis software (RevMan 5.3; Cochrane Collaboration, Copenhagen, Denmark). Both intervention type and control group were variables; therefore, to further establish trends in treatment intervention type, within-group standard mean difference effect size[29] was also calculated for all studies where sufficient data were present. Interventions were grouped by type: standard physical therapy and strength training; OGT; PBWSTT; treadmill training; gait training enhanced with virtual reality and feedback; and miscellaneous. If at least two studies in treatment groups reported the same outcome, weighted mean effect estimates were calculated, on the basis of sample size and standard deviation. An effect size of 0.2 to 0.49 was interpreted as a small effect, 0.5 to 0.79 a medium effect, and over 0.8 a large effect size.[30]

RESULTS

Summary of studies

The comprehensive search of the databases identified 799 articles meeting search criteria (Fig. 1). Seven hundred and forty-two articles were removed after screening of title and/or abstract. The main reasons for exclusion included no training intervention reported, incorrect intervention type (e.g. robotic assistive devices or electrical stimulation), and incorrect target population (e.g. diagnosis and age). Consequently 57 articles were selected for full-text review.

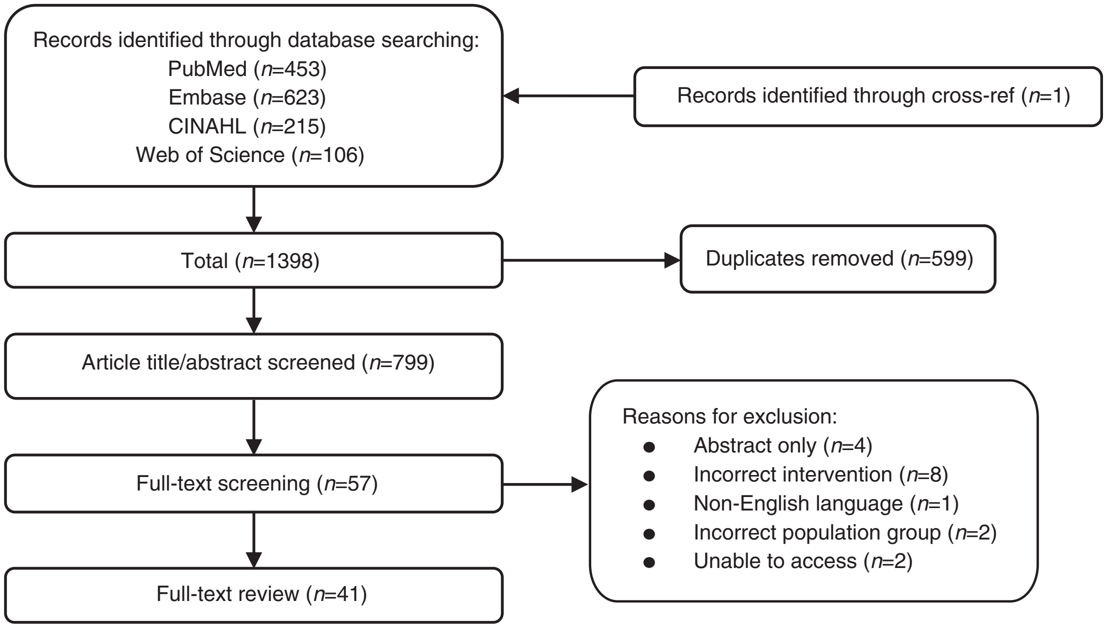


Figure 1: Article selection flow.

Of these, 41 articles were deemed to meet the inclusion/exclusion criteria;[22,31–70] reasons for exclusion of 16 articles[71–87] are noted in Figure 1. One study population was reported in two articles;[62,63] to avoid duplicates, results were reported as Provost et al.[63] A summary of all the studies' characteristics is given in Table II. Table III includes details of the methodological quality of group studies in levels I to III. There were no level I evidence group studies identified, 11 level II studies, four level III studies, 15 level IV studies, and nine level V studies. Quality of studies ranged from very poor (1 out of 17)[58] to high-quality randomized controlled trials (16 out of 17).[47] There were only two single-subject research design studies identified: one of level II[70] and one level V.[50] Interrater reliability of scoring for quality of methodological design between reviewers was substantial (κ=0.65).

In total, 453 participants were included in level I to III studies; sample size ranged from 14 participants[40] to 95 participants.[32] A further 166 participants were included within level IV and V studies, ranging from individual case reports[37–39,42,59] to a sample size of 17.[67] The reported diagnosis of all patients was CP, most commonly described as spastic, while other studies reported athetoid[40,43] and ataxic[64] CP. Walking ability of participants was also variable, with all GMFCS levels included. Only studies involving PBWS included participants in GMFCS levels IV and V.[34,39,52,56,68,70] All studies reported outcome measures related to gait that could be explored in the International Classification of Functioning, Disability and Health domains categorized by body function and structure, activity, and participation. Table IV summarizes this information for level I to III studies; outcomes of level IV and V studies can be found in Appendix S2 (online supporting information).

For level II and III studies, duration of intervention ranged from 2 weeks[47] to 12 weeks.[22,31,32,41,49,52] Training intensity varied from as little as 15 minutes gait training three times per week,[44] up to 1-hour sessions five times per week.[49] One study was not clear about the training intensity provided.[59]

Walking speed

Walking speed was the most commonly reported gait outcome, reported as an outcome measure in 14 level II and III studies.[22,31,32,35,40,41,44,47,49,52,58,61,65,68] The measure of walking speed varied, with seven studies reporting the outcome of the standardized 10-metre walk test,[32,35,40,41,61,65,68] six studies reporting walking speed during three-dimensional overground gait analysis,[22,31,47,49,52,58] and the remaining study reporting self-selected walking speed on a treadmill.[44] All studies, except one,[68] reported a within-group increase in walking speed, with 11 reporting this to be a significant within-group improvement; one further study did not report within-group statistical outcomes.[22] Effect sizes for all studies are shown in Figure 2. The MCID for increase in walking speed (0.1m/s), was achieved after intervention in 12 studies.[22,31,32,35,41,44,47,49,52,58,61,65] Level IV and V studies supported this positive effect of increase in walking speed as a result of gait training. Fifteen of these studies reported walking speed, with nine reporting an increase over the MCID.[33,34,50,51,55,57,59,60,63] One further study reported no change after a brief period of gait training with added ankle load.[69] Persisting positive effects were noted in

Table II: Summary of all study characteristics

Group study	Level of evidence; research design	Population	Total number	Age range; mean (SD)	Intervention	Control intervention
Abdel-Aziem and El-Basatiny[31]	II RCT	Spastic CP GMFCS level: E: I=6/II=9 C: I=7/II=8	n=30 E=15 C=15	10–14y E: 11y 7mo (1y 5mo) C: 11y 6mo (1y 4mo)	OGT backward walking Plus 1h conventional PT Duration: 25min/×3wks/12wks	OGT forward walking Plus 1h conventional PT Duration: 25min/×3wk/12wks
Aviram et al.[32a]	III Matched controlled trial	Spastic CP GMFCS level: E: II=31/III=12 C: II=39/III=13	n=95 E=43 C=52	14–21y E: 16y 7mo (1y 8mo) C: 16y 8mo (1y 10mo)	TT with speed increases based on perceived intensity. Includes warm up and cool down exercises. Duration: 40min/×30 sessions over 12wks	Group resistance training: strength/ balance/endurance. Duration: 40min/×30 sessions over 12wks
Cho et al.[35]	II RCT	Spastic CP GMFCS level: E: I=3/II=1/III=5 C: I=3/II=2/III=4	n=18 E=9 C=9	4–16y E: 10y 2mo (3y 5mo) C: 9y 5mo (3y 10mo)	TT with virtual reality. Speed increased to 60% maximum heart rate. Plus 30min conventional PT Duration: 30min/×3wk/8wks	TT without virtual reality. Speed increased to 60% maximum heart rate. Plus 30min conventional PT Duration: 30min/×3wk/8wks
Chrysagis et al.[22]	II RCT	Spastic CP GMFCS level: E: I=3/II=4/III=4 C: I=2/II=5/III=4	n=22 E=11 C=11	13–19y E: 15y 11mo (2y) C: 16y 1mo (1y 6mo)	TT. Speed increased as tolerated. Speed starts at previous session max. Additional verbal feedback given. Duration: 30min/×3wk/12wks	Conventional PT Duration: 45min/×3wk/12wks
Dodd and Foley[40]	III Matched controlled trial	Spastic CP/athetoid CP GMFCS level: E: III=2/IV=5 C: III=2/IV=5	n=14 E=7 C=7	NR E: 8y 5mo (2y 5mo) C: 9y 5mo (2y 10mo)	PBWSTT, BWS reduced until gait deteriorated. Plus conventional PT Duration: 30min/×2wk/6wks	Conventional PT, no PBWSTT Duration: 30min/×2wk/6wks
Emara et al.[41]	II Randomized group study	Spastic CP GMFCS level: E: III=10 C: III=10	n=20 E=10 C=10	NR E: 6y 7mo (8mo) C: 6y 11mo (7mo)	TT Plus 40min conventional PT Duration: 30min/×3wk/12wks	OGT with PBWS Plus 40min conventional PT Duration: 30min/×3wk/12wks
Gharib et al.[44]	II RCT	Spastic CP GMFCS level: E: II=15 C: II=15	n=30 E=15 C=15	10–13y E: 11y 11mo (1y 1mo) C: 11y 2mo (1y 1mo)	TT with audio/visual feedback Plus 30min conventional PT Duration: 15min/×3wk/12wks	Conventional PT Duration: 30min/×3wk/12wks
Grecco et al.[46]	II RCT	CP (type NR) GMFCS level: E: I=5/II=8/III=3 C: I=8/II=7/III=2	n=33 E=16 C=17	3–12y E: 6y 10mo (2y 6mo) C: 6y (1y 6mo)	TT. Speed increased as tolerated. Duration: 30min/×2wk/7wks	OGT with assistive device if used. Duration: 30min/×2wk/7wks
Grecco et al.[47]	II RCT	Spastic CP GMFCS level: E: II=8/III=4 C: II=8/III=4	n=24 E=12 C=12	5–10y E: 7y 10mo (3y) C: 8y (2y 2mo)	TT with anodal tDCS applied over the primary motor cortex. Duration: 20min/×5wk/2wks	TT with sham tDCS. Duration: 20min/×5wk/2wks
Hamed et al.[49]	II RCT	Spastic CP GMFCS level: NR	n=30 E=15 C=15	3–12y E: 7y (8mo) C: 7y 1mo (8mo)	OGT with pedometer audio feedback. Plus conventional PT Duration: 60min/×5wk/12wks	Conventional PT Duration: 60min/×5wk/12wks
Johnston et al.[52]	II RCT	Spastic CP GMFCS level: E: II=1/III=9/IV=4 C: II=1/III=6/IV=5	n=26 E=14 C=12	6–13y E: 9y 6mo (2y 2mo) C: 9y 5mo (2y 3mo)	PBWSTT home-based. Duration: 30min/×5wk/12wks	Strength and exercise training programme. Duration: 30min/×5wk/12wks

Table II: Continued

Group study	Level of evidence; research design	Population	Total number	Age range; mean (SD)	Intervention	Control intervention
Kwak[58]	III Controlled group study	Spastic CP GMFCS level: NR	n=25 E=16 C=9	6–20y NR	OGT with rhythmic auditory feedback. Duration: 30min/×5wk/3wks	Conventional PT Duration: NR
Malarvizhi et al.[61]	III Quasi-experimental group	Spastic CP GMFCS level: NR	n=30 E=15 C=15	8–16y NR	PBWSTT Plus conventional PT Duration: 8wks, intensity unclear	Conventional PT Duration: 8wks, intensity unclear
Swe et al.[65]	II RCT	Spastic CP/athetoid CP GMFCS level: E: II=10/III=5 C: II=8/III=7	n=30 E=15 C=15	NR E: 13y 1mo (3y 6mo) C: 13y 4mo (3y 4mo)	PBWSTT Plus conventional PT Duration: 30min/×2wk/8wks	OGT with own assistive device. Plus conventional PT Duration: 30min/×2wk/8wks
Willoughby et al.[68]	II RCT	Spastic CP GMFCS level: E: III=5/IV=7 C: III=3/IV=11	n=26 E=12 C=14	5–18y E: 10y 5mo (3y 1mo) C: 11y 2mo (4y 2mo)	PBWSTT Plus conventional PT Duration: 30min/×2wk/9wks	OGT Plus conventional PT Duration: 30min/×2wk/9wks
Levels IV and V						
Baram and Lenger[33]	IV Case series	CP (type NR) GMFCS level: NR	n=10	6–25y 12y 1mo (6y 7mo)	OGT with auditory and visual feedback on spatiotemporal stepping. Target increased step length. Duration: 20min	n/a
Begnoche et al.[34]	IV Case series	Spastic CP GMFCS level: I=2/III=1/IV=2	n=5	2–9y 6y 5mo (2y 2mo)	PBWSTT gait facilitated by therapist if required. Plus 2h conventional PT Duration: 15–35min/×4wk/4wks	n/a
Colborne et al.[36]	IV Case series	Hemiplegic spastic CP GMFCS level: NR	n=7	8–15y 10y 7mo (2y 10mo)	OGT visual biofeedback of calf muscle activation during gait. Duration: 30 biofeedback trials/×8 sessions over 4wks	n/a
Gorter et al.[45]	IV Test–retest repeated measures design	CP (type NR) GMFCS level: I=12/II=1	n=13	NR 9y 11mo (1y 1mo)	Functional therapy focused on functional tasks. Includes TT, OGT and bicycle exercise. Duration: 30min/×2wk/9wks	n/a
Grecco et al.[48]	IV Cohort study (no control)	CP (type NR) GMFCS level: II=9/III=6	n=15	NR 11y 1mo (3y 5mo)	TT, after surgery. Plus 2×1h sessions of PT/wk Duration: 30min/wk/12wks	n/a
Hodapp et al.[51]	IV Case series	Spastic CP GMFCS level: I=1/II=3/III=3	n=7	5–15y 9y 8mo (NR)	TT speed increased as tolerated. Duration: 10min/day/10 consecutive days	n/a
Kassover et al.[53]	IV Case series	Spastic diplegic CP GMFCS level: NR	n=4	5–8y 6y 2mo (NR)	OGT. Auditory feedback device to improve heel contact. Duration: 1h training at clinical setting, 1h/day/8wks home use	n/a
Kim et al.[54]	IV Pilot study	Spastic CP GMFCS level: I=9/II=3	n=12	5–15y 9y 6mo (4y 5mo)	Backward walking TT at self-selected speed. Duration: 20min/×3wk/8wks	n/a

Table II: Continued

Group study	Level of evidence; research design	Population	Total number	Age range; mean (SD)	Intervention	Control intervention
Kott et al.[55]	IV Pilot study	Spastic CP GMFCS level: I=3/II=2	*n*=5	4–10y 7y 5mo (2y 4mo)	TT, intensity based on HR. Virtual reality used to increase engagement. Duration: 9h over 3–4wks	n/a
Kurz et al.[57]	IV Case series	Spastic CP GMFCS level: II=4/III=8	*n*=12	11–16y 8y 8mo (4y)	PBWSTT. BWS reduced and speed increased based on HR. Duration: 20min/×2wk/12wks	n/a
Kurz et al.[56]	IV Case series	Spastic CP GMFCS level: III=3/IV=1	*n*=4	11–16y 13y 8mo (2y)	PBWSTT. Target increased steps per session, BWS reduced. Duration: 30min/×2wk/6wks	n/a
Provost et al.[63b]	IV Pilot	Spastic CP GMFCS level: I=6	*n*=6	6–14y NR	PBWSTT. Goal to reduce BWS from 30% to 0%. Duration: 30min/×6wk/2wks	n/a
Schindl et al.[64]	IV Open, non-randomized, baseline-treatment study	Spastic/ataxic CP GMFCS level: NR	*n*=10	6–18 11y 6mo (NR)	PBWSTT. Speed increased as tolerated, BWS reduced until gait deteriorated. Duration: 30min/×3wk/12wks	n/a
Willerslev-Olsen et al.[66]	IV Case series	CP (type NR) GMFCS level: I=7/II=6/III=4	*n*=17	5–14y 9y 5mo (NR)	TT with incline of at least 5%. Incline was primary target for increase during home-based training. Duration: 30min/day/4wks	n/a
Willerslev-Olsen et al.[67c]	IV Case series	CP (type NR) GMFCS level: I=7/II=6/III=4	*n*=16	5–14y 9y 7mo (NR)	TT with incline of at least 5%. Incline was primary target for increase during home-based training. Duration: 30min/day/4wks	n/a
Level V						
Crowley et al.[37]	V Case report	Spastic diplegic CP GMFCS level: III	*n*=1	6y	TT. Goal of therapy was increased walking time and speed. Plus conventional PT 1h/wk Duration: 30min/×3wk/6wks	n/a
Day et al.[38]	V Case report	Spastic tetraplegic CP GMFCS level: NR	*n*=1	9y	PBWSTT, BWS reduced until gait deteriorated and speed increased. Duration: ~1h sessions/44 sessions over 25wks	n/a
DiBiasio et al.[39]	V Case report	Spastic quadriplegic CP GMFCS level: IV	*n*=1	18y	PBWSTT. Walking in 3min bouts, number of bouts per session decided by fatigue level. Duration: 9–15min/×2wk/6wks	n/a
Farrell et al.[42]	V Case report	CP (type NR) GMFCS level: NR	*n*=1	10y	OGT with PBWS. Plus 60min conventional PT Duration: 30min/×3–5wk/4wks	n/a

Table II: Continued

Group study	Level of evidence; research design	Population	Total number	Age range; mean (SD)	Intervention	Control intervention
Flodmark[43]	V Pilot	Spastic CP=5 Athetosis=2 GMFCS level: NR	n=7	7–12y NR	OGT. Auditory biofeedback on knee angle. Positive or negative feedback given depending on gait type. Duration: 5 sessions on 25m walking track/×4wk/7wks	n/a
Lee et al.[59]	V Case report	Spastic CP GMFCS level: NR	n=1	11y	Progressive walk to run technique training. Speed at which transition from walk to run trained with verbal feedback. Duration: 60min/×2wk/12wks	n/a
Lee[60]	V Case report	Spastic CP GMFCS level: NR	n=2	11y	Virtual reality feedback on functional movements relating to gait. Duration: 8wks. Unclear intensity	n/a
Simão et al.[69]	V Case report	Spastic CP GMFCS level: I=3	n=3	8–12y NR	TT with added load (40/50/60% lower limb weight) on ankle. Duration: 5min walking with each load, consecutive days	n/a
Single-subject research design						
Su et al.[70]	II Two-period crossover study	Choreo/Dystonic CP GMFCS level: II=1/III=1/IV=5/V=3	n=8	8–14y 10y 11mo (2y 4mo)	PBWSTT. Goals to increase speed and decrease BWS as tolerated. Duration: 25min/×2wk/12wks	OGT Duration: 30min/×2wk/12wks
Hegarty et al.[50]	V Pilot	Spastic CP GMFCS level: I=1/II=4	n=5	9–16y 10y 11mo (2y 4mo)	PBWSTT. Speed based on 75% max heart rate. BWS reduced 5% every week. Duration: 30min/×3wk/6wks	n/a

[a]Control group presented in study treated as intervention in current review. [b]Same population as Phillips et al.[62] [c]Same population as Willerslev-Olsen et al.[66] RCT, randomized controlled trial; CP, cerebral palsy; GMFCS, Gross Motor Function Classification System; E, experimental group; C, control group; OGT, overground gait training; PT, physical therapy; TT, treadmill training; NR, not reported; PBWSTT, partial body weight support treadmill training; BWS, body weight support; PBWS, partial body weight support; tDCS, transcranial direct current stimulation; n/a, not applicable.

Table III: Results of methodological quality of articles for group and single-subject research design studies

Group study	Level of evidence; research design	Total score	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Abdel-Aziem and El-Basatiny[31]	II RCT	11/17	1	1	1	1	1	0	0	0	1	0	1	0	1	1	1	1	0
Aviram et al.[32]	III Controlled trial	9/17	1	0	0	0	0	1	1	1	0	0	1	0	1	1	0	1	1
Cho et al.[35]	II RCT	12/17	1	1	1	0	1	1	1	0	1	0	1	0	1	1	1	1	0
Chrysagis et al.[22]	II RCT	15/17	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1
Dodd and Foley[40]	III Controlled trial	11/17	1	0	0	0	1	0	1	1	0	0	1	1	1	1	1	1	1
Emara et al.[41]	II RCT	9/17	1	1	1	0	1	0	1	0	1	0	0	0	1	1	0	1	0
Gharib et al.[44]	II RCT	11/17	1	1	1	1	1	1	0	0	1	0	0	0	1	1	1	1	0
Grecco et al.[46]	II RCT	15/17	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	1
Grecco et al.[47]	II RCT	16/17	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
Hamed et al.[49]	II RCT	11/17	0	0	1	1	1	1	0	0	1	0	1	0	1	1	1	1	0
Johnston et al.[52]	II RCT	9/17	1	1	1	0	0	1	0	0	0	0	1	1	1	0	0	1	1
Kwak[58]	III Controlled trial	1/17	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Malarvizhi et al.[61]	III Quasi-experimental controlled trial	4/17	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0
Swe et al.[65]	II RCT	14/17	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	0
Willoughby et al.[68]	II RCT	12/17	1	1	1	0	1	1	1	0	1	0	1	0	1	0	1	1	1
Single-subject research design																			
Su et al.[70]	II Two-period crossover	5/14	1	1	0	1	0	0	0	1	0	1	0	0	0	0	–	–	–

RCT, randomized controlled trial.

studies with follow-up measurements from 1 month[31,47,52] up to 6 months[32] after cessation of intervention; however, one study was contrary to this trend, showing a decline in walking speed at 14 weeks follow-up after resuming normal activities.[68]

Walking endurance

Walking endurance was reported as a gait outcome in seven level II and III studies.[32,35,40,46,47,65,68] The measure of endurance varied, including the 2-minute walk test,[35] 6-minute walk test,[32,46,47,65] and 10-minute walk test.[40,68] One study reported a reduction in distance walked after intervention;[68] all other studies reported an increase in distance travelled after intervention. However, there was wide variation in effect size. Supporting studies[39,45,48,50,56,63] also found evidence for improved endurance as a result of gait training, with only one case study reporting a decrease in distance covered after intervention.[39] Retention of improved endurance was variable, with improvements both persisting[32,46,47] and regressing.[68]

Gross motor function

GMFM or subcategories of this measure were reported in 11 studies.[22,31,32,35,41,46,47,52,61,65,70] Three studies reported the overall GMFM score, of which two found a statistically significant within-group change and intergroup improvement favouring intervention,[32,61] in addition exceeding the reported MCID of 1.3,[28] while one study found no significant change in this measure.[52] Eight studies reported the walking dimension of the GMFM (dimension E),[31,32,35,41,46,47,65,70] with one reporting the sum of dimensions D and E.[22] All studies reported an increase in dimension E score by more than the MCID of 2.6.[28] Supporting the trend of improved GMFM dimension E, nine studies in levels IV and V showed improvements in gross motor function surpassing the MCID.[36,38,42,48,54,55,59,63,64] One study reported a significant improvement below the MCID,[57] while Crowley et al.[37] found no change in score in a single patient case report. Four studies reported lasting positive effects in gross motor function retained in follow-up from 1 month[31,46,47] up to 6 months after intervention.[32]

Other gait-related outcomes

While speed, endurance, and gross motor function were the most widely reported, further gait-related outcome measures were also investigated. Step length was a commonly reported spatiotemporal parameter, which increased in all

Table IV: Summary of results of gait-related outcome measures for studies in levels I–III

Study	Outcome of interest	Measure	ICF code	Results (follow-up)	SS (within-group)	SS (between-group)	MCID
Group study							
Abdel-Aziem and El-Basatiny[31]	Gross motor function	GMFM dimension D	AP d415	Improved score from baseline at post and follow-up (1mo)	SS, $p<0.001$	SS, $p=0.004$	Y
		GMFM dimension E	AP d450	Improved score from baseline at post and follow-up (1mo)	SS, $p<0.001$	SS, $p=0.042$	Y
	Walking speed	Self-chosen speed, gait analysis	AP d450	Increased speed from baseline at post and follow-up (1mo)	SS, $p<0.001$	SS, $p=0.028$[a]	Y
	Spatiotemporal gait	Step length	BF b770	Increased from baseline at post and follow-up (1mo)	SS, $p<0.001$	SS, $p=0.007$	Y
		Cadence	BF b770	Cadence decreased from baseline at post and follow-up (1mo)	SS, $p<0.001$	SS, $p=0.001$	—
		Stance phase	BF b770	Increase stance percentage from baseline at post and follow-up (1mo)	SS, $p<0.001$	SS, $p<0.001$	—
Aviram et al.[33b]	Gross motor function	GMFM total	AP d4	Improved score from baseline at post and follow-up (3mo)	SS, $p<0.05$	SS, $p=0.001$[a]	Y
		GMFM dimension D	AP d415	Improved score from baseline at post and follow-up (3mo)	SS, $p<0.05$	SS, $p=0.013$[a]	Y
		GMFM dimension E	AP d450	Improved score from baseline at post and follow-up (3mo)	SS, $p<0.05$	SS, $p=0.022$[a]	Y
		Timed up and go	AP d460	Increased speed from baseline at post and follow-up (3mo)	SS, $p<0.05$	SS, $p=0.014$[a]	Y
	Walking speed	10-min walk test (self-paced)	AP d450	Increased speed from baseline at post and follow-up (3mo)	SS, $p<0.05$	NS, $p=0.41$	Y
		10-min walk test (fast-paced)	AP d450	Increased speed from baseline at post and follow-up (3mo)	SS, $p<0.05$	NS, $p=0.30$	—
	Walking endurance	6-min walk test	AP d450	Increased distance from baseline at post and follow-up (3mo)	SS, $p<0.05$	NS, $p=0.31$	—
Cho et al.[35]	Gross motor function	GMFM dimension D	AP d415	Improved score from baseline	SS, $p<0.05$	SS, $p=0.007$	Y
		GMFM dimension E	AP d450	Improved score from baseline	SS, $p<0.05$	NS, $p=0.440$	Y
	Walking speed	10-min walk test	AP d450	Increased speed from baseline	SS, $p<0.05$	SS, $p=0.001$	Y
	Walking endurance	2-min walk test	AP d450	Increased distance from baseline	SS, $p<0.05$	SS, $p<0.001$	—
	Muscle strength	Knee flexion	BF b730	Increased strength from baseline	SS, $p<0.05$	SS, $p=0.016$	—
		Knee extension	BF b730	Increased strength from baseline	SS, $p<0.05$	SS, $p=0.017$	—
Chrysagis et al.[22]	Gross motor function	GMFM (dimensions D and E)	AP d4	Improved score from baseline	NR	SS, $p=0.007$	—
	Walking speed	Self-chosen speed, gait analysis	AP d450	Increased speed from baseline	NR	SS, $p<0.001$	Y
	Spasticity	Knee extensors	BF b735	Slight decrease in spasticity	NR	NS, $p=0.827$	—
		Ankle platarflexors	BF b735	Slight decrease in spasticity	NR	NS, $p=0.460$	—
Dodd and Foley[40]	Walking speed	10-min walk test	AP d450	Increased speed from baseline	SS, $p<0.05$	SS, $p=0.048$	N
	Walking endurance	10-min walk test	AP d450	Increased distance from baseline	NS	NS, $p=0.083$	—
Emara et al.[41]	Gross motor function	GMFM dimension D	AP d415	Improved score from baseline	SS, $p<0.001$	SS, $p=0.001$[a]	Y
		GMFM dimension E	AP d450	Improved score from baseline	SS, $p<0.001$	SS, $p=0.008$[a]	Y
		Five times sit to stand	AP d460	Increased speed from baseline	SS, $p=0.001$	NS, $p=0.26$	—
	Walking speed	10-min walk test	AP d450	Increased speed from baseline	SS, $p=0.001$	NS, $p=0.12$	Y
Gharib et al.[44]	Walking speed	Self-chosen speed, treadmill	AP d450	Increased speed from baseline	SS, $p<0.05$	NS, $p=0.19$	Y
	Spatiotemporal gait	Step length	BF b770	Increased step length (affected side)	SS, $p<0.05$	NS, $p=0.28$	—
		Step length	BF b770	Increased step length (non-affected side)	SS, $p<0.05$	NS, $p=0.15$	—
		Ambulation index	BF b770	Increased ambulation index	SS, $p<0.05$	SS, $p=0.001$	—
		Time of support	BF b770	More symmetrical time of support	SS, $p<0.05$	SS, $p=0.007$	—
Grecco et al.[46]	Gross motor function	GMFM dimension D	AP d415	Improved score from baseline at post and follow-up (1mo)	SS, $p<0.05$	SS, $p<0.001$	Y
		GMFM dimension E	AP d450	Improved score from baseline at post and follow-up (1mo)	SS, $p<0.05$	SS, $p<0.001$	Y
		Timed up and go	AP d460	Increased speed from baseline at post and follow-up (1mo)	SS, $p<0.05$	SS, $p=0.001$	Y
		PEDI	AP d	Improved score from baseline at post and follow-up (1mo)	SS, $p<0.05$	SS, $p=0.035$	—
	Walking endurance	6-min walk test	AP d450	Increased distance from baseline at post and follow-up (1mo)	SS, $p<0.001$	SS, $p=0.001$	—

Table IV: Continued

Study	Outcome of interest	Measure	ICF code	Results (follow-up)	SS (within-group)	SS (between-group)	MCID
Grecco et al.[47]	Gross motor function	GMFM dimension D	AP d415	Increased from baseline at post and follow-up (1mo)	NS, p=0.715	NR	Y
		GMFM dimension E	AP d450	Increased from baseline at post and follow-up (1mo)	NS, p=0.785	NR	Y
	Walking speed	Self-chosen speed, gait analysis	AP d450	Increased speed from baseline at post and follow-up (1mo)	SS, p<0.05	SS, p<0.05	Y
	Walking endurance	6-min walk test	AP d450	Increased distance from baseline at post and follow-up (1mo)	SS, p<0.001	SS, p<0.05	—
		Treadmill endurance test	AP d450	Improved performance on treadmill test at post and follow-up (1mo)	NS, p=0.117	NS	—
	Spatiotemporal gait	Cadence	BF b770	Increased cadence at post and follow-up (1mo)	SS, p<0.05	SS, p<0.05	Y
		Stride length	BF b770	No change in step length at post, slight decrease at follow-up (1mo)	NS	NS	Y
		Stance phase	BF b770	Slight increase in stance phase percentage at post and follow-up (1mo)	NS	NS	—
	Kinematics	Gait profile score	BF b770	Decrease in GPS at post and follow-up (1mo)	SS, p<0.05	SS, p<0. 05	Y
Hamed et al.[49]	Walking speed	Self-chosen speed, gait analysis	AP d450	Increased speed	SS, p<0.001	SS, p<0.001	Y
	Spatiotemporal gait	Stride length	BF b770	Increased stride length	SS, p<0.001	SS, p<0.001	Y
		Cadence	BF b770	Decreased cadence	SS, p<0.001	SS, p<0.001	Y
Johnston et al.[52]	Gross motor function	GMFM total	AP d4	No change in score	NS, p=0.31	NS, p=0.66	N
		PODCI global score	AP d4	Improved score, maintained at follow-up (1mo)	SS, p=0.003	NS, p=0.73	Y
		Motor control	AP d4	No change	NS	NS	—
	Walking speed	Self-chosen speed, gait analysis	AP d450	Increased speed, maintained at follow-up (1mo)	SS, p=0.008	NS	Y
	Spatiotemporal gait	Cadence	BF b770	Cadence increased, maintained at follow-up (1mo)	SS, p<0.001	NS	Y
		Stride length	BF b770	Inconsistent changes	SS, p<0.001	NS	—
	Spasticity	Spasticity	BF b735	No change	NS	NS	—
	Muscle strength	Strength	BF b770	No change	NS	NS	—
Kwak[58]	Walking speed	Self-chosen speed, gait analysis	AP d450	Increased speed	SS, p=0.016	NR	Y
	Spatiotemporal gait	Stride length	BF b770	Increased step length	SS, p=0.014	NR	—
		Cadence	BF b770	Variable because of different goal of feedback (patient-specific)	—	—	—
		Gait symmetry	BF b770	Improved gait symmetry	SS, p=0.048	NR	—
Malarvizhi et al.[61]	Gross motor function	GMFM total	AP d4	Improved score	SS, p<0.001	SS, p=0.03	Y
	Walking speed	10-min walk test	AP d450	Increased speed	SS, p<0.001	SS, p<0.001	Y
Swe et al.[65]	Gross motor function	GMFM dimension D	AP d415	Increased score	SS, p<0.001	NS, p=0.967	Y
		GMFM dimension E	AP d450	Increased score	SS, p<0.001	NS, p=0.931	Y
	Walking endurance	6-min walk test	AP d450	Increased distance	SS, p<0.001	NS, p=0.764	—
	Walking speed	10-min walk test	AP d450	Increased speed	SS, p<0.001	NS, p=0.244	Y
Willoughby et al.[68]	Walking endurance	10-min walk test	AP d450	Slightly reduced walking distance, further decline at follow-up (14wks)	NS, p=0.09	NS, p=0.097	—
	Walking speed	10-min walk test	AP d450	Reduced speed, further decline at follow-up (14wks)	NR	NS, p=0.194	N
	Functional performance	School Function Assessment Scale	AP d	No change in score, no change at follow-up (14wks)	NR	NS, p=0.133	—
Single-subject research design studies							
Su et al.[70]	Gross motor function	GMFM dimension D	AP d415	Improved score from baseline	SS, p=0.038	NS, p=0.303	Y
		GMFM dimension E	AP d450	Improved score from baseline	SS, p=0.030	NS, p=0.307	Y
		GMAE	AP d4	Improved score from baseline	SS, p=0.001	NS, p=0.114	—

[a]Favours control group. [b]Study control treated as intervention for purpose of review. ICF, International Classification of Functioning, Disability and Health; SS, statistically significant; MCID, minimal clinically important difference; GMFM, Gross Motor Function Measure; AP, activities and participation; BF, body function(s); NS, no significance; NR, not reported; PEDI, Pediatric Evaluation of Disability Inventory; PODCI, Pediatrics Outcomes Data Collection Instrument; GMAE, Gross Motor Ability Estimator.

studies.[32–34,36,47,49,52,54,57,58] Pediatric Evaluation of Disability Inventory (PEDI) score,[34,46] Paediatric Outcomes Data Collection Instrument,[52] timed up and go,[32,45,46] and five times sit to stand[41] were all found to have significantly improved. Although not directly gait-related, additional outcomes that are of note include muscle strength and spasticity, as these are secondarily influential in gait in CP. Knee flexor and extension muscle strength were found to increase in one study,[35] while further studies reported no change.[52,56,57] No change in spasticity was reported as a result of gait training,[22,52] with one study reporting a reduction in spasticity and increased range of motion as a result of treadmill training with incline.[66]

Meta-analysis

Direct comparison of gait training versus standard physical therapy was only feasible for reported outcome measures of walking speed, where sufficient studies could be compared. Meta-analysis revealed a significant medium effect towards increased walking speed was found to favour gait training over standard physical therapy (d=0.79, p=0.04; Fig. 3).

Figure 2 shows the within-group effect size for each gait outcome reported, and pooled effect of treatment type: physical therapy and strength training; OGT; PBWSTT; treadmill training; gait training enhanced with virtual reality and feedback; and miscellaneous. The miscellaneous studies could not be considered to fit into other groups because of their diverse nature, including studies investigating backward walking,[31,54] OGT with PBWS,[41] treadmill training with transcranial direct current stimulation,[47] treadmill training with ankle load,[69] and treadmill training after surgery.[48] While interpretation of results of this meta-analysis should be treated with caution, a tendency towards increased effect size of gait training on walking speed can be observed in gait training groups with gait training enhanced with virtual reality and feedback. The effects are less apparent in endurance and GMFM dimension E, where treadmill training shows a tendency towards a larger effect compared with standard physical therapy, PBWSTT and OGT. However, there are limited data reported in gait training enhanced with virtual reality and feedback studies to compare these gait outcomes. Outliers could be identified, particularly in the miscellaneous group, with one study comparing treadmill training with OGT with PBWS; both groups showed a large effect for walking speed and GMFM dimension E.[41] While the OGT with PBWS group found a larger effect size in walking speed, the experimental treadmill training group reported greater effects on GMFM dimension E.[41] The use of treadmill training with the addition of transcranial direct current stimulation to stimulate motor learning was also reported to show outlying large effects across all reported outcome measures.[47] In one study, treadmill training was grouped in the miscellaneous category as the intervention was shortly after surgery[48] and therefore outcomes could be partly attributed to natural progression after surgical intervention. Indeed, the large effects noted for walking speed and GMFM dimension E may reflect this.

Adverse events

Only one study noted any adverse events as a result of treatment, reporting minor adverse events for three children: two complained of leg discomfort off the treadmill, which resolved without intervention; and one child developed a blister on their foot while wearing an orthosis during the induction period.[52] No other studies reported adverse events relating to treatment.

DISCUSSION

With advancement of technology and exponential growth in research publications, there is an increase in the number of reported interventions to treat gait limitations in children and young adults with CP. Best practice in rehabilitation requires adequate evidence before an intervention can be considered appropriate in a patient population. In the present systematic review, we sought to update the current state of reported evidence about the use of functional gait training in children and young adults with CP and attempted to identify the most effective methods of gait training interventions. This review identified 41 studies reporting the effects of functional gait training on walking ability in children and young adults with CP.

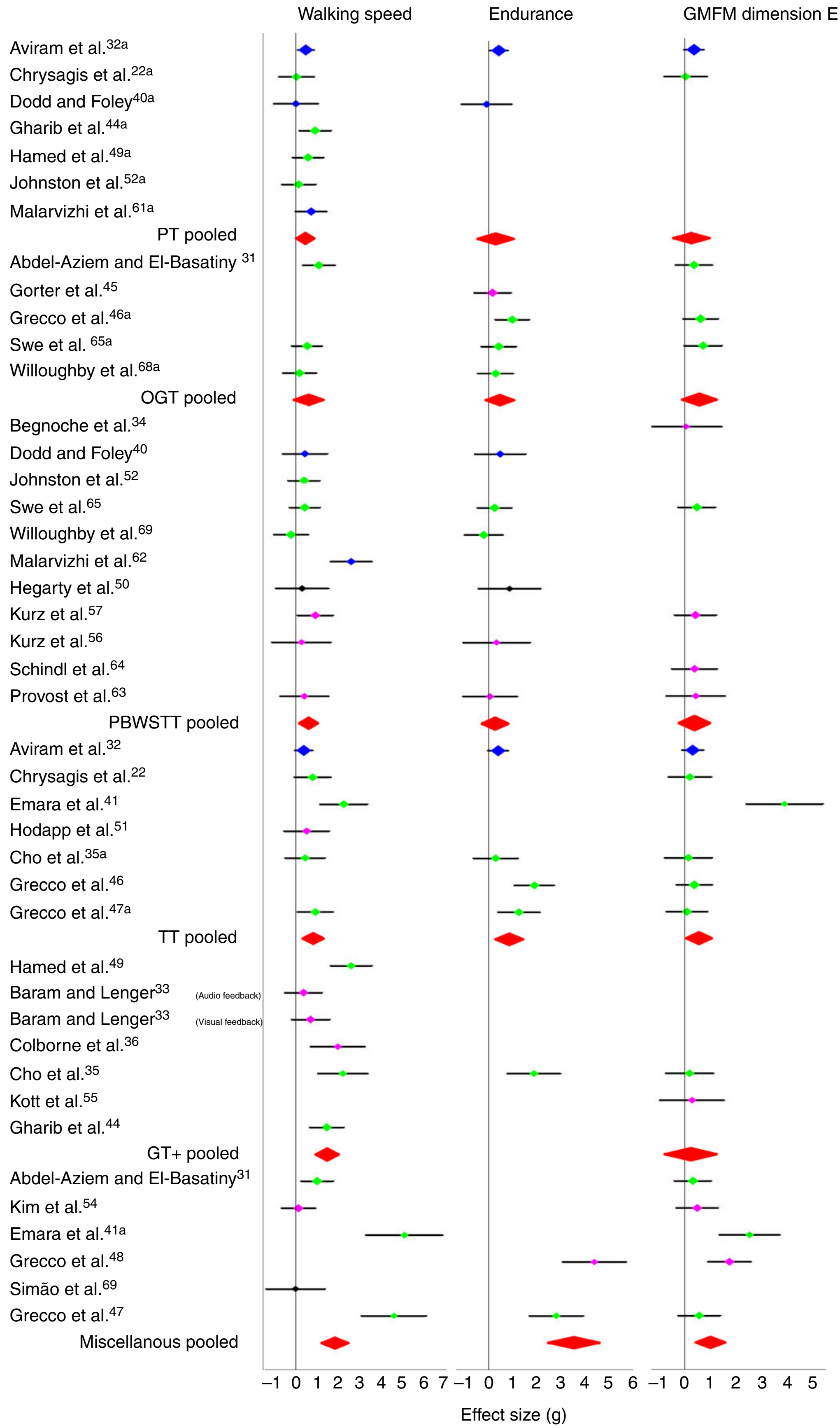
Relating to the main aim of this review, the preponderance of evidence supports a positive effect of functional gait training to improve walking ability in children and young adults with CP across a breadth of age range and severity of mobility limitation. Improvements were widely reported in walking speed and gross motor function, exceeding the clinically important amount. Additional gains were also reported in walking endurance, spatiotemporal gait parameters, and functional mobility. The direct comparison between intervention and standard therapy was limited by the wide variation in study control choice and reported gait outcomes. Comparison was only possible for walking speed, where meta-analysis revealed a significant moderate effect towards increased walking speed with gait training intervention. Aviram et al.[32] was the only study included in the meta-analysis to favour standard therapy over gait training. While this study involved many participants, the sample was not randomized and the study control group intervention was considered to be strength training; therefore, it cannot have the highest level of evidence, and there is some risk of bias. Further, the strength training intervention used in this study might also have differed from standard physical therapy in that the intervention had a focus on functional goals, with many functional exercises such as squats and stair climbing incorporated in a holistic circuit-training approach. In addition, the training programme was conducted in a group setting, increasing socialization and motivation. As both groups were found to improve, this study highlights the importance of including functional tasks in interventions targeting walking limitation. Johnston et al.[52] reported a similar strength training control group, with a target of functional performance; however, outcomes significantly favoured gait training. Both interventions lasted 12 weeks, with Johnston et al. providing somewhat greater training intensity. The main difference can be seen to be the patient demographic: Johnston et al. included younger patients of slightly higher gait limitation and so used a home-based PBWSTT system, whereas Aviram et al.[32] used treadmill training with no support and speed increased on the basis of perceived exertion. It should be noted that both groups in each study reported a significant increase in walking speed after intervention, which was maintained for the gait training group[32,52] and strength group[32] in the follow-up period. The persistence of effect of gait training intervention in follow-up was established with studies reporting lasting positive effects.[31,32,36,37,45,47,52,66–68] It could be speculated that improvements in walking ability after intervention allowed increased participation in daily life that would consolidate effects.

The results of this review confirm that functional gait training in children and young adults with CP is a safe treatment intervention to target improvement of outcomes relating to walking ability. In total, 619 children and young adults were included in selected studies and only one study reported minor adverse events relating to gait training.[52] The current review synthesized a broad range of literature reporting the use of gait training, identifying several previously unreported randomized controlled trials and well-controlled group studies. As such, this review provides greater evidence in support of gait training over standard therapy for improving functional walking ability in CP, with a significant moderate effect on walking speed. This finding is also supported in a recent review by Moreau et al., specifically investigating gait speed, reporting that gait training resulted in a large effect size of 0.92 (95% CI 0.19–1.66), significantly greater than that of strength training (effect size 0.06, 95% CI −0.12 to 0.25).[88] However, two studies involving electromechanical gait training interventions[85,89] were also included in their meta-analysis along with studies comparing PBWSTT with OGT,[68] which was excluded from the presented meta-analysis.

The review attempted to provide further insight on the efficacy of treatment by grouping within-group estimated effects by intervention type. This analysis should act as a guide for therapists developing patient-specific rehabilitation strategies, to identify studies or groups of studies that show large effects on gait outcomes. The use of treadmill training in rehabilitation has been suggested to result in increased stepping repetition and intensity of gait training.[13] Gait speed can be precisely controlled and thus intensity can be progressively increased by the therapist to maximize outcomes. The results of the present review seem to follow this convention, with studies using treadmill training showing a tendency towards higher effects in improving gait speed and endurance than standard therapy, strength training, and OGT. Emara et al.[41] report particularly large effects of treadmill training on walking speed and GMFM dimension E; this may be partly explained by the low reported standard deviation of outcome, possibly because of the relatively homogenous sample recruited. Indeed, in the same study they even showed that OGT with PBWS resulted in a larger effect and concluded that OGT is more likely to simulate natural walking to provide greater effect on locomotor abilities than treadmill training; however, 12 weeks was required to elicit significant benefits.[41] The children in this study were in GMFCS level III and those undergoing treadmill training intervention did not have body weight support; therefore the potential benefit of unloading of the limbs for these children may have been the cause of improvement as opposed to the overground effects.

It has been suggested that the use of biofeedback and virtual reality enhances patient outcomes in rehabilitation, and the studies identified in this review seem to support this.[33,35,36,43,44,53,60,73] Cho et al.[35] compared treadmill training with treadmill training enhanced with virtual reality, and a significantly larger effect was noted in the virtual reality group in walking speed and endurance. The authors concluded that virtual reality provides strong motivation, increasing concentration for participants and leading to enhanced outcomes.[35] This is supported in the findings of Gharib et al.,[44] who showed that treadmill training with feedback on gait performance leads to large effect increases in walking speed. These authors surmised the addition of feedback supports motor learning and modification of acquired motor patterns through experiential learning. In rehabilitation of neurological impairment, such as CP, patients often have impaired sensory feedback networks.[44] Two studies investigated the effects of feedback in the form of rhythmic auditory stepping cues to drive an improved stepping pattern,[33,49] with Hamed et al.[49] showing strong benefits over standard physical therapy. Baram and Lenger[33] hypothesized that the gait improvement they reported in patients using feedback-enriched gait training

Figure 2: Forest plot showing within-group standardized mean effect sizes (Hedges' *g*) and 95% confidence intervals for effects of gait training on walking speed, Gross Motor Function Measure (GMFM) dimension E, and endurance. Studies are grouped by gait training intervention (standard physical therapy [PT] and strength; overground gait training [OGT]; partial body weight support treadmill training [PBWSTT]; treadmill training [TT]; gait training enhanced with virtual reality/feedback [GT+]; and miscellaneous). Red diamonds show the weighted pooled effect estimate of intervention type on outcome measure. Size of diamond represents weighting towards pooled effect, while colour indicates the level of evidence associated with the study (green, II; blue, III; magenta, IV; black, V). All groups in the studies are represented; [a]Control group. [Colour figure can be viewed at wileyonlinelibrary.com].


Walking speed
Endurance
GMFM dimension E
Aviram et al.[32a]
Chrysagis et al.[22a]
Dodd and Foley[40a]
Gharib et al.[44a]
Hamed et al.[49a]
Johnston et al.[52a]
Malarvizhi et al.[61a]
PT pooled
Abdel-Aziem and El-Basatiny [31]
Gorter et al.[45]
Grecco et al.[46a]
Swe et al. [65a]
Willoughby et al.[68a]
OGT pooled
Begnoche et al.[34]
Dodd and Foley[40]
Johnston et al.[52]
Swe et al.[65]
Willoughby et al.[69]
Malarvizhi et al.[62]
Hegarty et al.[50]
Kurz et al.[57]
Kurz et al.[56]
Schindl et al.[64]
Provost et al.[63]
PBWSTT pooled
Aviram et al.[32]
Chrysagis et al.[22]
Emara et al.[41]
Hodapp et al.[51]
Cho et al.[35a]
Grecco et al.[46]
Grecco et al.[47a]
TT pooled
Hamed et al.[49]
Baram and Lenger[33] (Audio feedback)
Baram and Lenger[33] (Visual feedback)
Colborne et al.[36]
Cho et al.[35]
Kott et al.[55]
Gharib et al.[44]
GT+ pooled
Abdel-Aziem and El-Basatiny[31]
Kim et al.[54]
Emara et al.[41a]
Grecco et al.[48]
Simão et al.[69]
Grecco et al.[47]
Miscellanous pooled
–1 0 1 2 3 4 5 6 7
–1 0 1 2 3 4 5 6
–1 0 1 2 3 4 5
Effect size (g)

Study or subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. mean difference IV, Random, 95% CI
Aviram et al.[32]	0.82	0.26	43	0.94	0.32	51	16.4%	−0.40 [−0.81, 0.01]
Chrysagis et al.[22]	0.997	0.149	11	0.781	0.171	11	13.6%	1.30 [0.36, 2.23]
Dodd and Foley[40]	0.174	0.149	7	0.131	0.095	7	12.8%	0.32 [−0.73, 1.38]
Gharib et al.[44]	0.67	0.09	15	0.63	0.1	15	14.9%	0.41 [−0.32, 1.13]
Hamed et al.[49]	0.68	0.09	15	0.45	0.11	15	13.6%	2.23 [1.29, 3.16]
Johnston et al.[52]	0.62	0.31	14	0.5	0.39	12	14.5%	0.33 [−0.44, 1.11]
Malravizhi et al.[61]	0.92	0.068	15	0.78	0.101	15	14.2%	1.58 [0.75, 2.42]
Total (95% CI)			120			126	100.0%	0.79 [0.04, 1.53]

Heterogeneity: τ^2=0.84; χ^2=40.66, *df*=6 (P<0.001); I^2=85%
Test for overall effect: Z=2.07 (p=0.04)

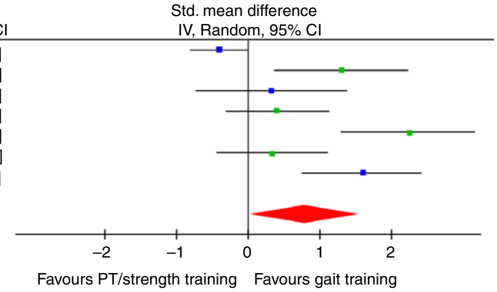


Figure 3: Forest plot for estimated effect on walking speed for gait training versus standard physical therapy (PT) and strength training. Size of point represents weighting towards pooled effect; colour indicates the level of evidence associated with the study (green, II; blue, III). [Colour figure can be viewed at wileyonlinelibrary.com].

was achieved through the enhancement of neuronal connections, bypassing impaired pathways. Description of feedback methodology was not always clear in the studies identified. Following motor learning theory, feedback should be provided in a faded approach to prevent an over-reliance on external feedback cues.[90] The added value that innovations in biofeedback and virtual reality have is an emerging topic and can be of particular benefit in paediatric rehabilitation.

To effectively target gait improvements with training, high intensity and prolonged training time are required to reach treatment goals. From the present synthesis of data, effective gait training programmes require as little as 10 sessions of 20 minutes of gait training over 2 weeks.[47] Although further research is required to establish best practice for duration and intensity of intervention, most commonly studies reported at least 6 weeks of gait training intervention with bi-weekly sessions lasting approximately 30 minutes. While this is achievable, particularly in home-based treadmill training,[52] for children and young adults with CP this may present a barrier for maintaining engagement in the process. Virtual reality and biofeedback provide powerful means to take the patient outside their regular treatment environment and to support them with engaging, informative motivation.

Novel technologies to enhance gait training can also be extended to the use of transcranial direct current stimulation. This approach was reported in one identified study and was shown to have a significant effect over standard treadmill training with sham transcranial direct current stimulation.[47] Low-level electrical stimulation is applied to the motor cortex to stimulate local synaptic efficacy. The authors hypothesized that treadmill training with transcranial direct current stimulation facilitates motor learning of a better gait pattern, as improved gait was maintained 1 month after the 10-day intervention protocol.[47] This is a novel approach in CP rehabilitation, and because results show promising outcomes, further studies should be undertaken to show the repeatability of this finding across a larger population before we are able to draw significant conclusions.

A common trend in the presented studies was the varied response from participants. There seemed to be responders and non-responders to treatment. Johnston et al.[52] highlight this as well, showing the differing effect of treatment among individuals, with some showing large, clinically important improvement while others show large, clinically important decline. The reasons for the differing response are inadequately characterized in the literature and are an important factor for progression of gait training as a treatment. Further research is required to establish why certain individuals benefit more from intense motor therapy whereas others do not. This is probably a complex and multifactorial issue; however, recent work investigating dynamic motor control may play a role in this. It has been shown that children with an ability to recruit a more complex, synergistic control of gait improved to a greater extent as a result of treatment interventions.[91] Perhaps it is the case that children and young adults with refined motor control will benefit more from gait training, irrespective of level of gait limitation.

A major limitation of this review is the lack of a consistent control group in the reported studies, along with the variable implementation of gait training as an intervention and inconsistently reported gait outcome measures. This limits the ability to draw strong conclusions in the comparison of intervention types and the effect on gait outcomes. For example, walking endurance is a widely reported outcome measure; however, the measure used to quantify this included the 2-minute walk test,[35] 6-minute walk test,[32,46,48,63,65] and 10-minute walk test.[40,56,68] The MCID for these tests is not well established, so future research should seek to follow a standardized approach and identify clinically important changes. Another limitation that is apparent in these findings is the frequency of studies in which participants underwent co-intervention, which is the addition of standard physical therapy in addition to the investigated treatment.[31,35,40,41,44,49,61,68] The grouping of within-group effects highlighted that standard therapy can also have a moderate positive effect on walking speed, endurance, and gross motor function. Therefore, in these instances we cannot categorically conclude that the reported changes are entirely attributed to the gait training intervention alone. Future studies should seek to isolate treatment and effect interaction with the use of strict intervention programmes and adequate concurrent controls.

From this review of literature, it can be concluded that functional gait training is a safe, feasible, and effective intervention to improve walking ability. There is strong evidence that functional gait training results in clinically important benefits for children and young adults with CP, with a therapeutic goal of improved walking speed. Meta-analysis suggests that gait training results in a larger positive effect than standard physical therapy. Further, there is weak yet relatively consistent evidence that gait training can also benefit walking endurance and gait-related gross motor function. The review has provided insight into the effects of the differing types of functional gait training that, to our knowledge, has not been done before, showing that the addition of virtual reality and feedback can increase patient engagement and magnify effect outcomes. At present there is no optimal training intensity and delivery; therefore clinicians should apply expert clinical judgement and monitor progress of patients individually. Future research should seek to directly compare gait training as an isolated intervention with standard physical therapy and compare treadmill training with functional gait training enhanced with virtual reality and feedback in well-designed randomized controlled trials, reporting standardized gait outcome measures and following International Classification of Functioning, Disability and Health recommendations.

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SUPPORTING INFORMATION

The following additional material may be found online:

Appendix S1: Quality appraisal questions for group and single-subject research design studies, and data extraction forms.

Appendix S2: Summary of results of gait-related outcome measures for study levels IV–V.

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RESUMEN

LA EFICACIA DEL ENTRENAMIENTO DE LA MARCHA FUNCIONAL EN NIÑOS Y ADULTOS JÓVENES CON PARÁLISIS CEREBRAL: UNA REVISIÓN SISTEMÁTICA Y METAANÁLISIS

OBJETIVO El objetivo de esta revisión sistemática fue investigar los efectos del entrenamiento de la marcha funcional en la capacidad de caminar en niños y adultos jóvenes con parálisis cerebral (PC).
MÉTODO La revisión se realizó utilizando una metodología estandarizada, buscando en cuatro bases de datos electrónicas (PubMed, Embase, CINAHL, Web of Science) literatura relevante publicada entre enero de 1980 y enero de 2017. Los estudios incluidos incluyeron entrenamiento con un enfoque en practicar activamente la tarea de caminar como una intervención, y a su vez; reportando medidas de resultado relacionadas con la capacidad para caminar.
RESULTADOS Se identificaron 41 estudios, entre ellos 11 estudios aleatorios controlados. Existe una fuerte evidencia de que el entrenamiento de la marcha funcional resulta en beneficios clínicamente importantes para los niños y adultos jóvenes con PC, con un objetivo terapéutico de mejorar la velocidad de marcha. Se encontró que el entrenamiento de la marcha funcional tiene un efecto positivo moderado sobre la velocidad de la caminata comparado con la terapia física estándar (tamaño del efecto 0.79, $p = 0.04$). Además, existe evidencia más débil, pero relativamente consistente, de que el entrenamiento de la marcha funcional también puede beneficiar la resistencia al caminar y la función motora gruesa relacionada con la marcha.
INTERPRETACIÓN Existe evidencia prometedora de que el entrenamiento de la marcha funcional es una intervención segura, factible y efectiva para mejorar la capacidad de caminar en niños y adultos jóvenes con parálisis cerebral. La incorporación de realidad virtual y retroalimentación biológica puede aumentar el compromiso del paciente con la intervención, y por lo tanto; magnificar los efectos.

RESUMO

EFICÁCIA DO TREINO FUNCIONAL DE MARCHA EM CRIANÇAS E JOVENS ADULTOS COM PARALISIA CEREBRAL: UMA REVISÃO SISTEMÁTICA E META-ANÁLISE

OBJETIVO O objetivo da presente revisão sistemática foi investigar os efeitos do treino funcional de marcha na habilidade de caminhar em crianças e jovens adultos com paralisia cerebral (PC).
RESULTADOS Quarenta e um estudos foram identificados e onze estudos randomizados e controlados foram incluídos. Há uma forte evidência de que o treinamento funcional da marcha resulta em benefícios clinicamente importantes para crianças e jovens adultos com PC, com objetivo terapêutico de melhorar a velocidade de caminhada. Encontrou-se um efeito positivo moderado com relação ao treinamento funcional da marcha em comparação com a fisioterapia convencional (tamanho do efeito 0,79, $p=0{,}04$). Além disso, encontramos evidências mais fracas, entretanto relativamente consistentes de que o treinamento funcional da marcha também pode beneficiar a resistência ao caminhar e a função motora grossa relacionada à marcha.
INTERPRETAÇÃO Há evidências promissoras de que o treinamento funcional da marcha é uma intervenção segura, viável e efetiva para atingir uma maior capacidade de caminhada em crianças e adultos jovens com PC. A adição de realidade virtual e biofeedback pode aumentar o engajamento do paciente e ampliar os efeitos encontrados.